Integration of geotechnical engineering and rainfall data into landslide hazard map in Thailand

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ABSTRACT

It was found that the frequency of the landslide events in Thailand is increasing sharply for the last decade starting from 1996-2006. The assumptions of the cause of increasing number of landslide for the past decade are 1. Landslide actually occur more often 2. Mismanagement of land use in the hazard areas 3. Both reason as indicated. Landslide hazard zoning shall be the solution in order to reduce number of losses. Various organizations have contributed their effort in making their own landslide hazard maps of Thailand. However, different landslide susceptibility factors were considered by different organizations. Factors considered are related directly to their expertise in each organization. Geotechnical engineering method was used by Geotechnical Engineering Research and Development center (GERD), Kasetsart University, however that method, even though accurate, is not fully appropriate to use in large area since details input required. Weighting factor method has proved to be suitable for large zoning area. Various factors that indicated landslide potential were considered in the analyses including the new factor, the geotechnical engineering properties of residual soil such as strength reduction, which hasn't been considered by any. In order to include this factor in the hazard mapping analysis, appropriate laboratory testing was designed to determine the properties that can indicate the landslide potential of each type of residual soil. As for rainfall factor, the rainfall accumulations of various return periods were used instead of using the average rainfall intensity or annual rainfall precipitation. Various landslide hazard maps were produced based on 3 days accumulated rainfall of different return period used for analyses. GIS tool was used for map making.

KEYWORDS: Landslide hazard map, Geotechnical engineering, Landslide

1. INTRODUCTION

Landslide hazard map of Thailand has been done mostly by weighting factor method. Various factors that indicated landslide potential were considered in the analyses, however the geotechnical engineering properties of residual soil such as strength reduction hasn't been considered by any. In order to include this factor in the hazard mapping analysis, appropriate laboratory testing was designed to determine the properties that can indicate the landslide potential of each type of residual soil.

2. LANDSLIDE EVENTS IN THAILAND

Geotechnical Engineering Research and Development center (GERD), Kasetsart University has developed landslide database of Thailand which contain of the 36 years period information of the previous landslide events starting from 1970. The example of the database output in GIS format is shown in Fig. 1. It was found that the frequency of the landslide events is increasing sharply for the last decade starting from 1996-2006. The assumptions of the cause of increasing number of landslide for the past decade are 1. Landslide actually occur more often 2. Mismanagement of land use in the hazard areas 3. Both reason as indicated. Fig. 2 and 3 show the landslide frequency and direct damage cost of the events that has value greater than and less than 100 million baht, respectively. Furthermore, table 1 shows number of people who loss their lives.

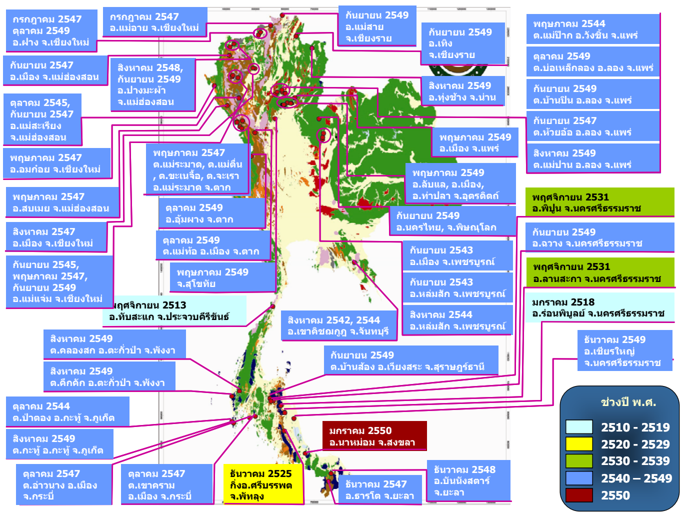


Fig. 1 Landslide events in Thailand (GERD, 2006)

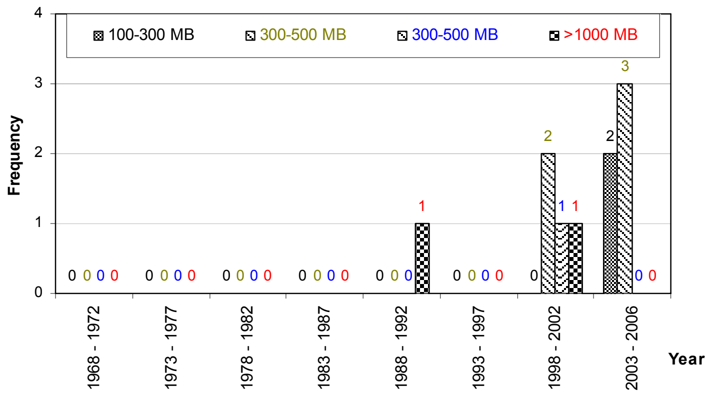


Fig. 2 Direct damage cost of greater than 100 million baht events in Thailand (Suttisak, 2007)

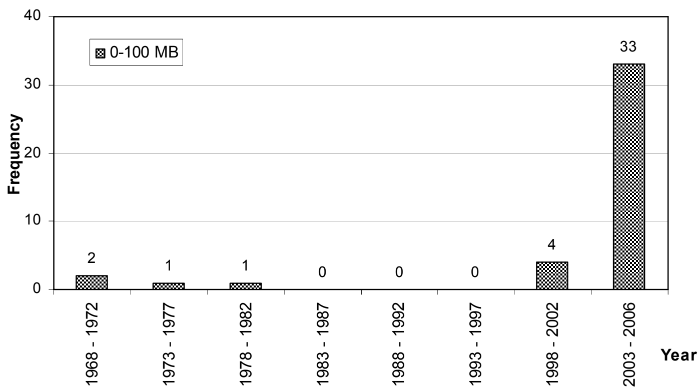


Fig. 3 Direct damage cost of less than 100 million baht events in Thailand (Suttisak, 2007)

Table 1 Number of casualties from landslide events in Thailand since 1970 (Suttisak, 2007)

Year	Casulties	Damage Cost,MB	Casulties Per Year	Damage Cost Per Year
2510 - 2520	0.00	0.00	0.00	0.00
2521 - 2530	0.00	0.00	0.00	0.00
2531 - 2540	230.00	1000.00	23.00	100.00
2541 - 2549	304.00	3585.60	33.78	398.40

3. GEOLOGIC CONDITION OF LANDSLIDE THAILAND

Fig. 1 shows geological map of Thailand which contains various group of rock. In order to study the effect of rock type on landslide hazard, similar type of rock, based on its formation, has been grouped together to obtain 8 rock group as shown in Fig. 4. The 8 rock groups are Group 1: Carboniferous-Permian granite has area of 0.74% Group 2: Jurassic-Cretaceous granite has area of 1.84% Group 3: Jurassic granite has area of 4.55% Group 4: Volcanic rock and other intrusive rock such as basalt, andesine, diorite etc. It has area of 2.81% Group 5: Sedimentary rock such as sandstone and mudstone, it has area of 44.69% Group 6: Metamorphic rock has area of 6.12% Group 7: Quantanary sediment has area of 35.98% Group 8: Limestone has area of 3.26%. Since rock group 7 and 8 has very low potential of landslide, therefore they haven't been considered in the study.

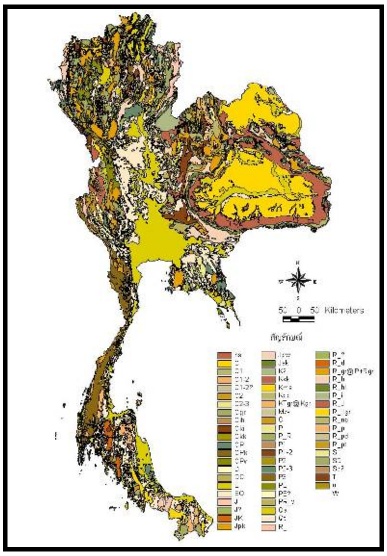


Fig. 4 Geological map of Thailand (Department of Mineral Resources, 1987)

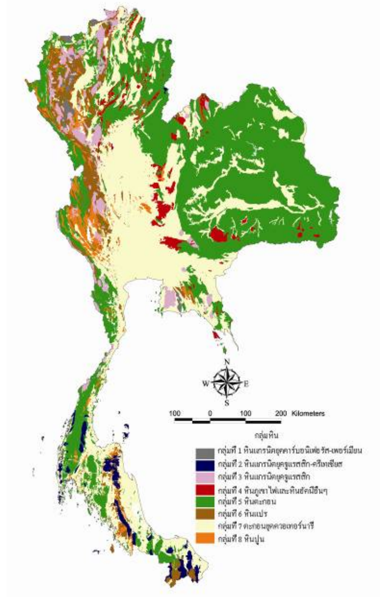


Fig. 5 Landslide rock group of Thailand (Suttisak et al., 2007)

Considering the landslide events and their rock group, percent of landslide frequency of each rock group can be analyzed as shown in Fig. 5. However, it will be more appropriate to consider the landslide frequency of each rock group based on their area as shown in Fig. 6. From the figure, we can see that landslide has occurred mostly in the Jurassic granite, based on the unit area.

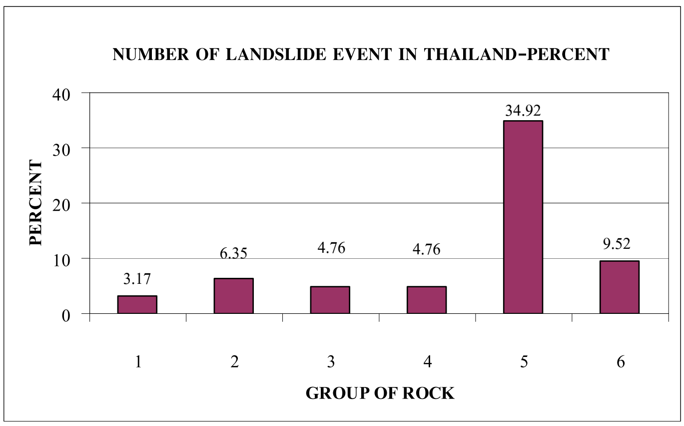
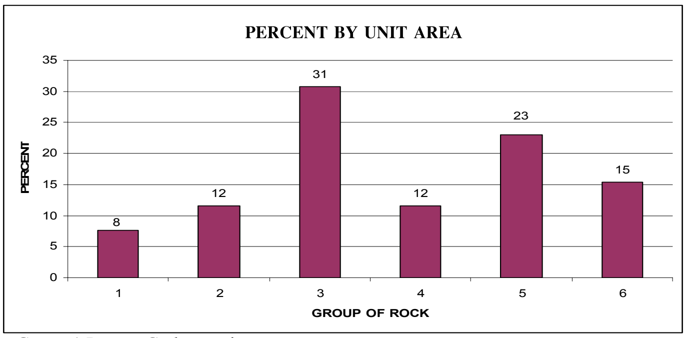


Fig. 6 Number in percent of landslide events in Thailand classified by frequency of occurring in each rock group (Suttisak et al., 2007)



Group 1 Permo-Carb. granite
Group 2 Jurassic-Cretaceous granite
Group 3 Jurassic granite
Group 4 Volcanic and other plutonic rock
Group 5 Sandstone, shale, mudstone, conglomerate and chert
Group 6 Metamorphic rock

Fig. 7 Number in percent by unit area of landslide events in Thailand classified by frequency of occurring in each rock group (Suttisak et al., 2007)

4. LANDSLIDE HAZARD MAP OF THAILAND

Landslide hazard mapping in Thailand were mostly done by weighting factor method using GIS technique. Table 2 shows the organization that has produced landslide hazard map. It can be seen that different landslide susceptibility factors were considered by different organizations. Factors considered are related directly to the expertise of each organization. Geotechnical engineering method was used by Geotechnical Engineering Research and Development center (GERD), Kasetsart University, however that method is not fully appropriate to use in large area since details input required.

Table 2 Factors considered by various organizations for landslide hazard analysis

Method/ Organization	FACTORS RELATED TO LANDSLIDE															
	ROCK TYPE	LANDFORM (SLOPE)	RAINFALL	RAINFALL 5 return	LANDUSE / LAND COVER	ELEVATION	GEOLOGY	TOPOGRAPHIC	THERMALOGY	INVENTORY	WATERSHED	DRAINAGE	WETNESS	SOIL DEPTH	GROUNDWATER	ENGINEERING SOIL PROPERTIES
1. Weighting factor																
1.1 WICHAI (1995)	✓	✓	✓		✓	✓										
1.2 DLD	✓	✓	✓		✓		✓									
1.3 FRC (KU)			✓				✓	✓	✓	✓						
1.4 DMR		✓	✓			✓	✓				✓	✓	✓			
1.5 Thassanapak (2001)	✓	✓	✓		✓	✓	✓					✓				
1.6 GERD (KU)	✓	✓	✓	✓	✓	✓	✓					✓				✓
2. Geotechnical																
2.1 GERD (KU)		✓	✓	✓	✓		✓						✓	✓	✓	

DLD : Department of Land Development
FRC : Foresty Reseach Center, Kasetsart University
DMR : Department of Mineral Resource
GERD : Geotechnical Engineering Research and Development Center, Kasetsart University

5. FACTORS CONSIDERED

This paper is presenting the method for corporation of geotechnical engineering data into landslide hazard map by using weighting factor method. This is part of the study project of Department of Mineral Resources and done by Geotechnical Engineering Research and Development Center, Kasetsart University. The study area is in the 6 provinces in the southern Thailand which has been affected by 2004 tsunami event. They are Phuket, Ranong, Trang, Phan-Gna, Satun and Krabi. Factors considered include: 1. Landform (slope and elevation) 2. Geologic condition (rock type and linearment zone) 3. Land use 4. Distance from surface water 5. Soil characteristics 6. Rainfall intensity and 7. Geotechnical engineering properties of residual soil. Factor 1 to 5 will not discuss in detail here since they are common factors considered for landslide hazard analysis. Rainfall intensity and geotechnical engineering properties factor is discuss below.

6. SIMULATION OF SHEAR STRENGTH LOSS IN RESIDUAL SOIL

In order to consider geotechnical engineering data for the landslide hazard analysis, three properties of residual soil were investigated: 1. strength reduction due to increasing of moisture content 2. soil plasticity and 3. grain size distribution. 220 landslides were investigated in the study area. 118 samples of residual soil were collected by KU-miniature sampler (Fig 8). The soil sampler was designed to ease the sampling of the residual soil especially in the landslide area (Mairaing et al., 2005). Since area ratio of the sampler is about 18 percent, x-ray analyses were done in this study to ensure the limited disturbance of soil samples (Fig 9).

Fig. 8 KU-miniature sampler (Mairaing et al., 2005)

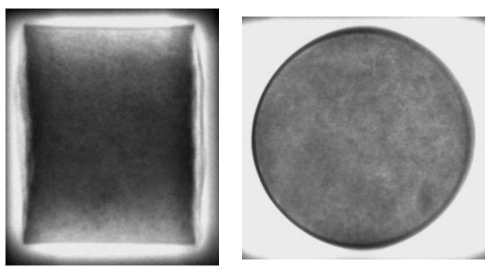


Fig. 9 X-Ray analysis of soil disturbance from KU-miniature sampler

Since there were quite a number of samples to be tested, the strength reduction due to the increasing of moisture content was studied by using Strength Reduction Index test (SRI)(Soralump, 2006). The test simulates the behavior of strength loss during the rainfall. The testing is done by comparing the effective shear strength of residual soil in natural moisture condition and in soaked condition. Soil strength was determined by direct shear testing. Constant normal stress was applied in all samples. The output of SRI is shown as the percent reduction of shear strength which is used an index for comparing the behavior of residual soil from different rock group. The effective shear strength will never used for stability analysis since the testing method is not accurate enough for detail analysis. Fig 10 and 11 shows the example of the result from SRI test. Beside the main output shown, during the soaking process, the collapse behavior of soil samples were monitor for future analysis (Fig. 12).

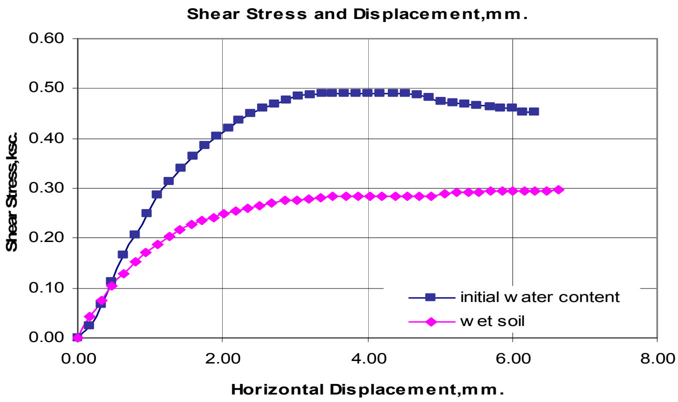


Fig. 10 Strength reduction behavior from SRI test (Suttisak et al., 2007)

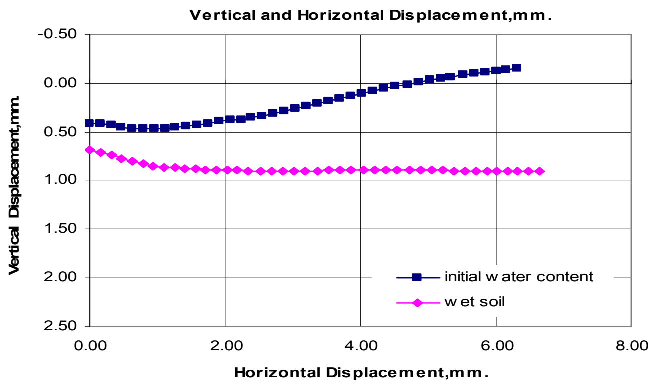


Fig. 11 Change in vertical displacement from SRI test (Suttisak et al., 2007)

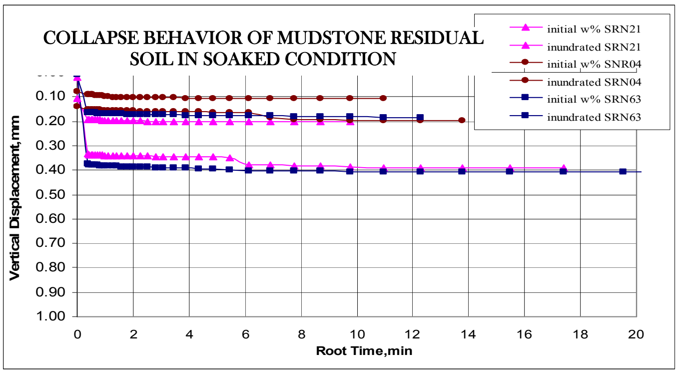


Fig. 12 Collapse behavior of mudstone residual soil after soaked (Suttisak et al., 2007)

Beside SRI test, plastic index test and grain size distribution analysis were also done. Based on rock group classification discussed above, the study area consists of rock group 2,3,5,7 and 8. Group 7 and 8 is not considered since it has low landslide hazard potential. As for rock group 2, 3 and 5, the dominate rock type are granite, pebbly mudstone, shale and sandstone or siltstone. Therefore, the rock type factor, considering in the landslide hazard mapping analysis of this study, was considered 4 rock types based on dominate rock.

The results of SRI test, PI value and grain size distribution analysis of residual soil of those rocks were used to compare the landslide hazard potential. The results of those analyses are shown in Fig. 13 to 15.

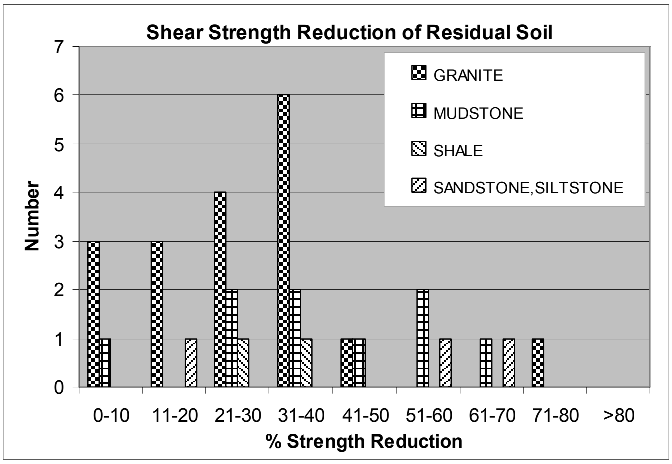


Fig. 13 Percent of shear strength reduction of residual soil of various rock type from SRI test

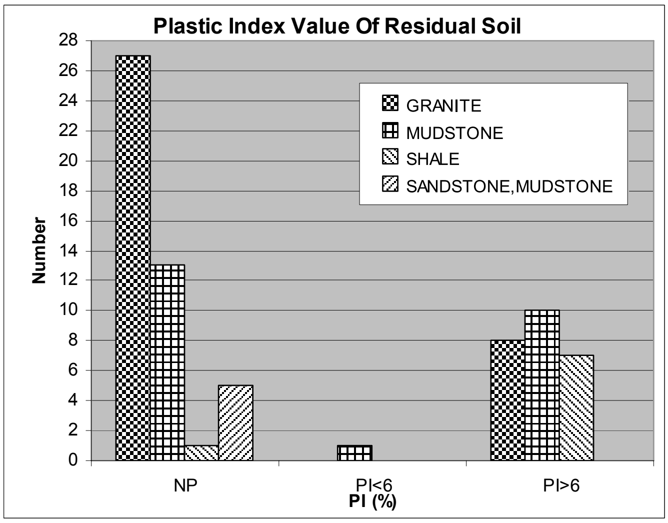


Fig. 14 Plastic index value of various type of residual soil

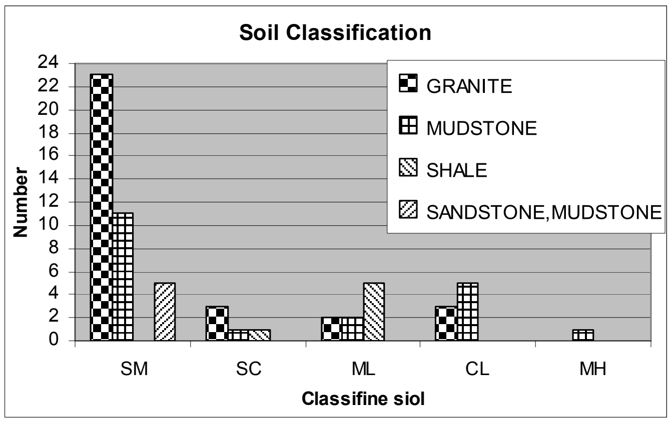


Fig. 15 Soil classification of residual soil

From the results shown above, the ranking of rock type based on potential of landslide hazard was done as shown in Table 3. This ranking was used to produced landslide hazard map in the studied area. Figure 16 shows the engineering soil properties map of Phuket

Table 3 Ranking of landslide potential properties

Unstable Soil Ranking	Rock Type	PI	Wet Sieve Analysis	USCS	Percent Strength Reduction
1	Sandstone	NP	Uniform grade	SM	>50%
2	Granite	NP	Well grade	SM	<50%
3	Mudstone	NP&PI>6	Gap grade	SM&CL	20%-70%
4	Shale	PI>6	Gap grade	ML	20%-40%

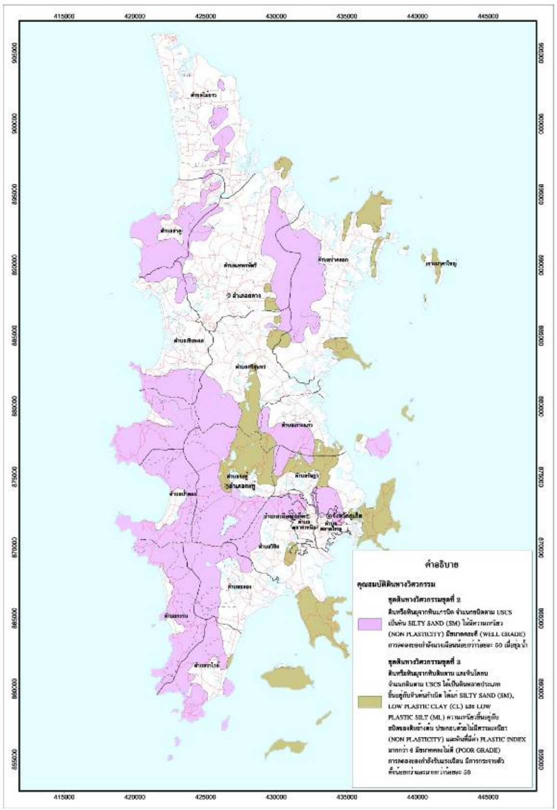


Fig. 16 Engineering soil properties of Phuket

7. TRIGERRING FACTOR AND HAZARD AREA ANALYSIS

The classification of hazard area has been done in GIS based. 50 by 50 meter grid size was used for each layer of information. The engineering soil properties factor was classified for different level of hazard as discussed in the previous section. Finally rainfall intensity factor was also considered. Rainfall precipitation data (about 20-30 years period)were obtained from 242 rain gauge stations in southern provinces in order to calculate 3 days accumulated rainfall in target area with various return period: 1, 5, 10, 20, 50 and 100 year (Fig. 17-18). The variation of calculated **accumulations within the study area was used to assign** hazard range with various return periods of precipitation.

Finally, after all factors have been analyzed to obtain landslide hazard level, all factors was compared in order to obtain appropriate weight by using weighting factor method. This procedure is an expert opinion method. Table 4 shows the result of weighting factor procedure. The weights and scores shown in Table 4 were applied to each grid cell in GIS in order to get the landslide hazard level of each grid cell. This process was done for all grid cells. Figure 19 shows the landslide hazard map of Phuket using 1 year return period of accumulated rainfall. As for other higher rainfall intensity (greater return period), when applied those in the landslide hazard model, the larger hazard area is obtained. Therefore, the landslide warning area shall be depended on the rainfall intensity at which we measure during the rainfall. 5 landslide hazard maps were then produced. The critical 3 days accumulated rainfalls of each rain gauge stations were calculated from the rainfall prediction analyses. The example of Phuget landslide hazard map and critical 3 days accumulated rainfall data is shown in Fig. 20. For convenient, various hazard areas calculated from various rainfall intensity or return periods can be plotted into one hazard map as shown in Fig. 21.

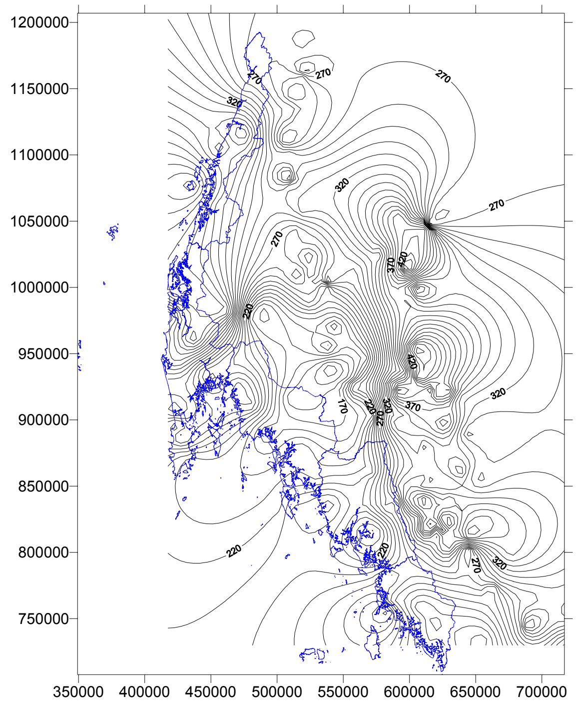


Fig. 17 Contour of rainfall precipitation in southern part of Thailand

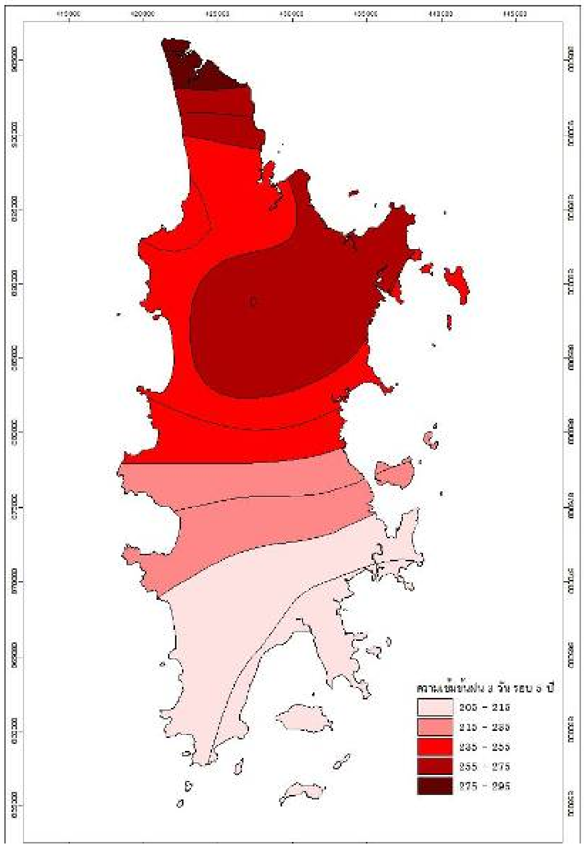
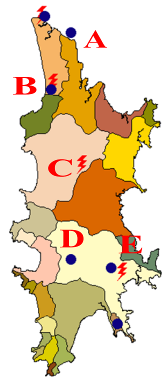


Fig. 18 Contour of 3 day accumulate rainfall for 1 year return period

Table 4 Weighting and rating used for making landslide hazard map of Phuket and others 6 provinces

Parameter	Weight Value		Rating Value		
	Parameter	Sub-parameter	Description		Rating (1-5)
1. Geology	5				
1.1 Rock Type		3	A. Granite Rock		5
			B. Shale/Mudstone		4
			C. Sandstone/Siltstone		3
			D. Quartzite, Sandstone and Siltstone		2
			E. Limestone/Dolomite		1
1.2 Lineament zone		2	A. Area inside lineament zone		5
			B. Area outside lineament zone		1
2. Landform	4				
2.1 Slope (%)		3	A. >70%		5
			B. 50-70%		4
			C. 30-50%		3
			D. 15-30%		2
			E. 0-15%		1
2.2 Elevation (meter)		1	A. >400 m		5
			B. 300-400 m		4
			C. 200-300 m		3
			D. 100-200 m		2
			E. 0-100 m		1
3. Surface drainage	2		A. Area inside surface drainage zone		4
			B. Area outside surface drainage zone		1
4. Soil characteristics	2		A. Gravel loam/Gravelly sand		5
			B. Sand		4
			C. Sandy loam		3
			D. Clayey loam/loam		2
			E. Clay, Mud		1
5. Land use and land cover	3		A. Agriculture area		4
			B. Urban and built-up area		3
			C. Other deforestation		2
			D. Forest area		1
6. Rainfall intensity	5		Return period 1	Return period 1,5,20,50,100 years	
			A. >203 mm.	>857 mm.	5
			B. 161-203 mm.	651-827 mm.	4
			C. 119-161 mm.	446-651 mm.	3
			D. 77-119 mm.	240-446 mm.	2
			E. 35-77 mm.	35-240 mm.	1
7. Engineering soil properties (in term of parent rocks)	4		A. Weathered Sandstone/Siltstone		5
			B. Weathered Granite Rock		4
			C. Weathered Shale/Mudstone		3
			D. Weathered Quartzite, Sandstone and Siltstone		2
			E. Weathered Limestone/ Dolomite		1



Return Period	Station				
	A	B	C	D	E
1	131	120	124	137	141
5	286	236	281	220	205
20	419	336	416	290	260
50	507	402	505	337	297
100	574	452	572	373	324

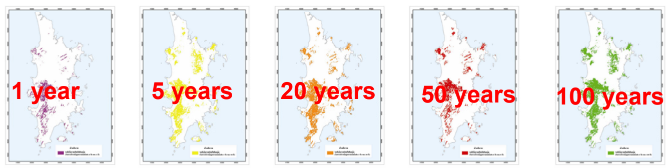


Fig. 20 Critical 3 days accumulated rainfall calculated for each rain gauge station and for different level of hazard map

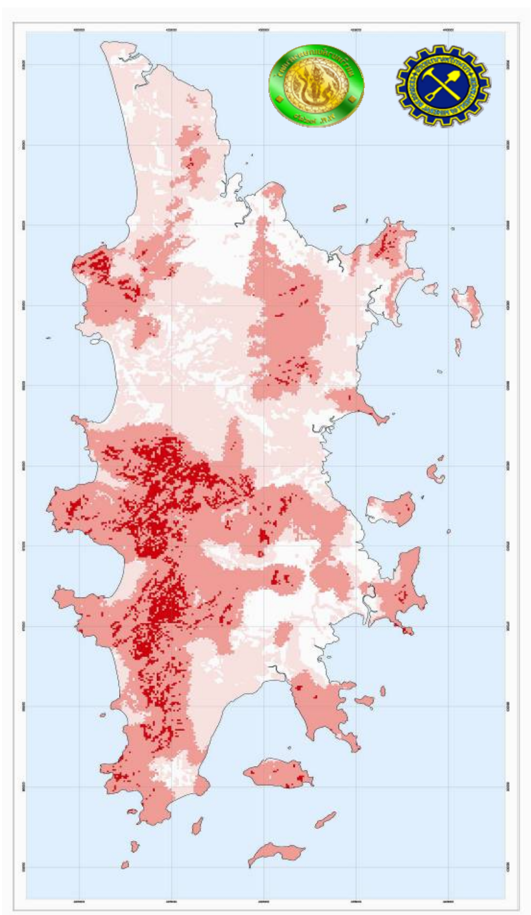


Fig. 19 Landslide hazard map of Phuket considering 1 year return period 3 days accumulate rainfall

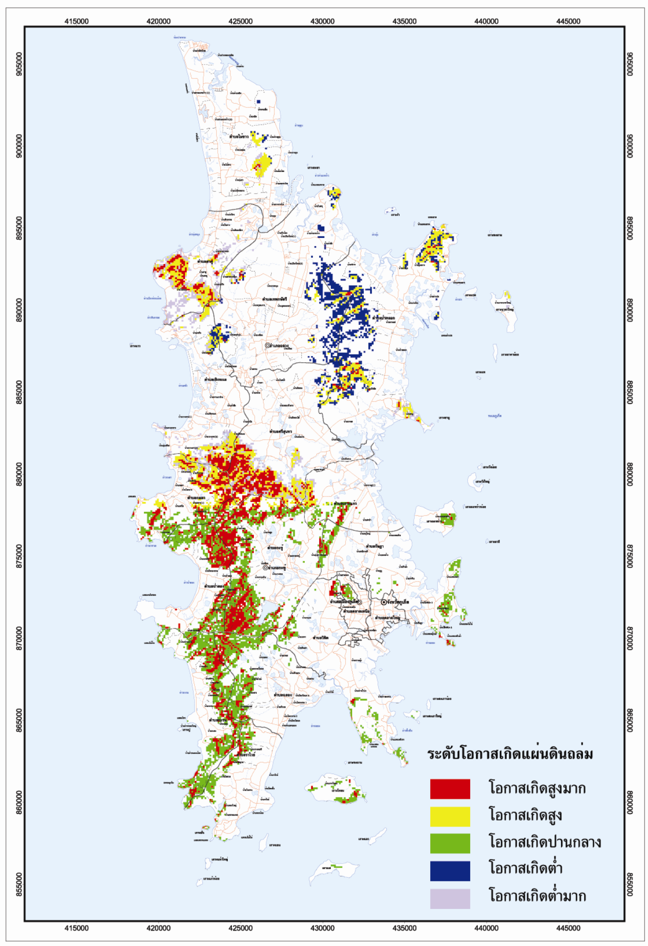


Fig. 21 Landslide hazard map using different level of rainfall intensity

8. CONCLUSIONS

The conclusions from the study can be drawn as follow:

1. Rock type in Thailand can be grouped into 6 groups based on possibility of landslide hazard.
2. Statistical shows that Jurassic granite in Thailand has highest landslide frequency per unit area from the 40 years landslide record.
3. In order to apply geotechnical engineering properties of residual soil into landslide hazard mapping, appropriate soil samplings and testing were done with every landslide potential rock groups in the study area. Engineering properties of each rock group were analyzed in term of area in order to be used as a layer in GIS analysis.
4. Strength reduction index (SRI), plastic index and grain size distribution were used as an index to consider the landslide potential of residual soil.
5. Accumulated rainfall precipitation in appropriate period of time, in this study is 3 days, were used to consider landslide hazard potential instead of using average rainfall per year.

9. ACKNOWLEDGEMENTS

Part of the data presents in this paper are obtained from “Landslide studies in 6 provinces affected by Tsunami” project which owned by Environmental Geology Division, Department of Mineral Resources.

10. REFERENCES

1. Department of Mineral Resources, 1987, “Geologic map of Thailand”
2. Geotechnical Engineering Research and Development center (GERD), 2006, “Landslide data base of Thailand”
3. Mairaing, W., Nongluck and Kulsuwan, B., 2005, “Landslide study in Pecthchaboon and Chantaburi”
4. Suttisak Soralump and Bunpoat Dulsuwan,2006, “Landslide Risk Prioritization of Tsunami Affected Area in Thailand”, International Symposium on Environmental Engineering and 5th Regional Symposium on Infrastructure Development in Civil Engineering., Philippines
5. Suttisak Soralump, Worawat Thowiwat and Warakorn Mairaing, 2007, “Shear Strength Testing of Soil Using for Warning of Heavy Rainfall-Induced Landslide”,
6. Proceeding of 12th National Conference on Civil Engineering. Phisanuklok, Thailand
7. Suttisak Soralump, 2007, “Corporation of Geotechnical Engineering data for landslide hazard map in Thailand”, EIT-JSCE Joint seminar on Rock Engineering, Bangkok, Thailand.